Technical Impact of Utilizing SPV Systems in Public Buildings in Gaza Strip:

A case study for Al- NASER hospital in Khanyounis

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Abstract— the paper discusses the prospects of utilizing solar Photovoltaic (SPV) system in a public building as a partial green solution to the shortage of generated energy in the Gaza Strip. The paper compares different types of SPV systems implemented worldwide and focuses on the pros and cons of each system while discussing the suitability and conformity of each system to local electrical environment in the Gaza Strip. The case study presented in this paper deals with retrofitting AL-NASER hospital in Khanyounis by 50.4kWp Building Applied Photovoltaic (BAPV) design featuring hybrid AC-coupled SPV system with battery and/or diesel generator backup as spinning reserves. When the grid is online, system's energy export and import is monitored by means of a bidirectional smart energy meter. In case the grid is offline, the SPV system shall be optionally coupled to the existing diesel generator through the use of a smart PV-diesel controller feeding the protected loads. Energy efficiency is also addressed by replacing existing inefficient lamps with LED lights resulting in about 60% power reduction dedicated to lighting. The aggregate PV system is expected to generate a total of approximately 73MWh per year contributing to major economic impacts for the hospital budget comprising reductions in diesel fuel consumption and electricity bill in addition to minimizing Green House Gas (GHG) emissions. The calculated annual savings shall be about 19kUSD while the investment cost shall be retrieved by the end of the first twelve years of operation.

Index Terms—SPV, BAPV, PV-diesel, hybrid AC coupling, solar fuel saver SFS, GHG emissions.

I- INTRODUCTION

The Gaza Strip is almost totally dependent on importing traditional energy such as petroleum products and electric energy. This alarming situation urges us to minimize the dependence on importing energy and focus on exploring indigenous energy resources and developing strategies to use the available local renewable energy resources efficiently. Electricity to the Gaza Strip is supplied by the Israeli Electric Corporation (IEC), the local generation power plant with a nominal installed capacity of 140MW, and power supply from Egypt. Table (1) summarizes the power supply and demand status in the Gaza Strip.

Table 1: Summary of Power supply and demand in the Gaza Strip

Source of power	First case	Second case
Power from the IEC	120MW	120MW
Power from the power plant	60MW	0MW
Power from Egypt	30MW	30MW
Total Available power	210MW	150MW
Peak demand in Gaza 2016	450MW	450MW
Percentage Deficit	50%	67%

Solar energy is closely related to the movement of the sun and location's latitude. Figure (1) shows that the average **yearly** sum of global irradiance is approximately over 2000kWh/m2 in Palestine.

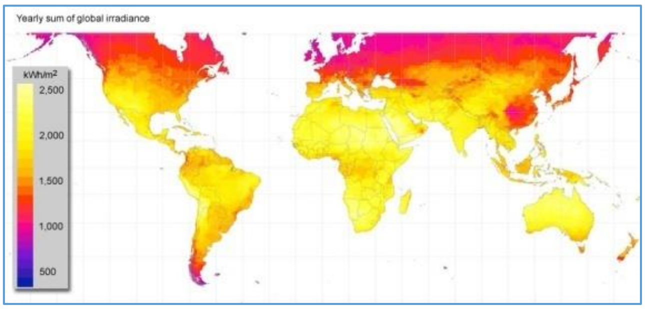


Figure 1: Average yearly sum of global solar irradiance

Figure (2) shows the effect of various tilt angles on solar insolation reception in Palestine. The optimum tilt angle is found to be 30°+/-5° which is almost equal to the local latitude. At this tilt angle, the average daily sum of solar irradiance is taken to be 5.61kWh/m2 and this value is used to estimate the energy generation of solar PV systems in the Gaza Strip.

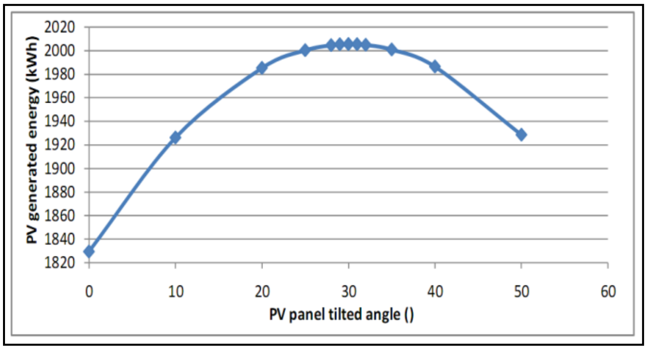


Figure 2: Effect of module tilt angle on PV generation

I.a: SPV system derate factors

Table (2) records the derate factors and the overall efficiency of the SPV system. An overall system derate factor of 72% shall be adopted in this paper. This value means that the AC power output is 72% of the nameplate DC power rating of the PV array evaluated at standard testing conditions (STC). This is a reasonable estimate adopted for modeling the AC energy production.

Table 2: Derate factors and overall system efficiency

Derate factor	Value
PV power tolerance	0.97
MPPT mismatch	0.96
PV module mismatch	0.98
Diodes and connections	0.99
DC wiring	0.95
AC wiring	0.98
Soiling/dust	0.97
System availability	0.99
shading	0.99
Total fixed derate factor	**0.8**
Total average variable derate factor due to temperature	**0.9**
Overall System derate	**0.72**

I.b: Explanation of derate factors

The derate factor for the **PV power tolerance** accounts for the accuracy of the manufacturer's nameplate rating. Field measurements of a representative sample of PV modules may show that the PV module powers are different than the nameplate rating or that they experienced light-induced degradation upon exposure (even crystalline silicon PV modules typically lose 2% of their initial power before power stabilizes after the first few hours of exposure to sunlight).

The derate factor for the **MPPT mismatch** is the efficiency of the MPPT inverter or charge controller.

The derate factor for **PV module mismatch** accounts for manufacturing tolerances that yield PV modules with slightly different current-voltage characteristics. Consequently, when connected together electrically they do not operate at their respective peak efficiencies.

The derate factor for **diodes and connections** accounts for losses from voltage drops across diodes used to block the reverse flow of current and from resistive losses in electrical connections.

The derate factor for **DC wiring** accounts for resistive losses in the wiring between modules and the wiring connecting the PV array to the inverter.

The derate factor for **AC wiring** accounts for resistive losses in the wiring between the inverter and the connection to the local utility service.

The derate factor for **soiling/dust** accounts for dirt, dust, or other foreign matter on the front surface of the PV module that reduces the amount of solar radiation reaching the solar cells of the PV module. Dirt accumulation on the PV module surface is location and weather dependent.

The derate factor for **system availability** accounts for times when the system is off due to maintenance and inverter and utility outages.

The derate factor for **shading** accounts for situations when PV modules are shaded by nearby buildings, objects, or other PV modules and array structure.

The derate factor due to **temperature** accounts for ambient temperature variations around the year

II - Possible Solar PV Systems in Gaza Strip

There are possible solar PV systems that can be applied in Gaza Strip. Each system has its pros and cons.

II.a: PV- grid integrated systems

In this system, solar power synchronizes with the grid thus reducing the amount of imported electricity. This type requires no batteries as shown in Figure (3)

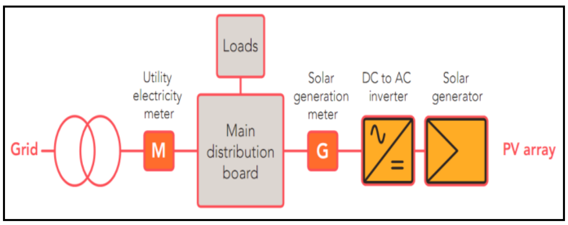


Figure 3: Block diagram of PV-grid integrated system

The PV – grid direct load profile is shown in figure (4).

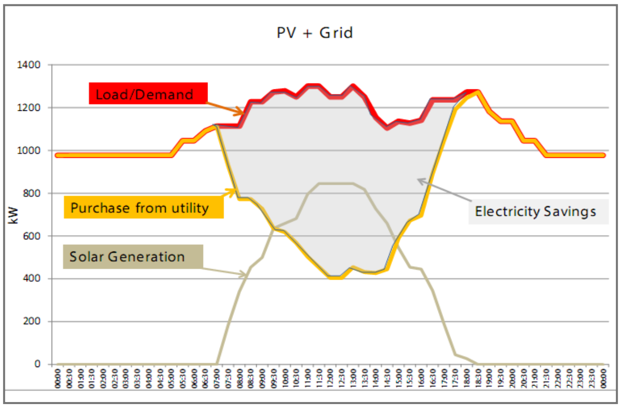


Figure 4: PV-grid integrated load profile

Table (3) lists the advantages and disadvantages of such system.

Table 3: Pros and cons of PV –grid direct systems

Type of system	Pros.	Cons.
System 1: **PV-Grid integrated system without battery backup**	• Simple system • Least cost due to no batteries integration • Does not require a room for grid or battery inverters • Reduces electricity bill	• Affected by grid instability. • Requires agreement of net-metering • Does not supply power during outage of grid power • It shall be off completely at time of wars when no main grid is present.

II.b: PV –diesel integrated systems

The price for PV systems has decreased by more than 60% in the last three years while fuel cost for diesel generators are constantly rising as shown in figure (5). This makes solar PV systems economical, sustainable and a clean energy share of the overall energy mix.

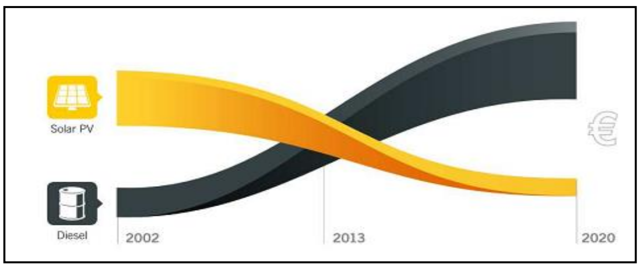


Figure 5: PV and diesel cost trend compared

In this type, the PV system reduces the energy consumed from the grid and also the amount of fuel consumed during power cuts. The single line diagram is shown in figure (6).

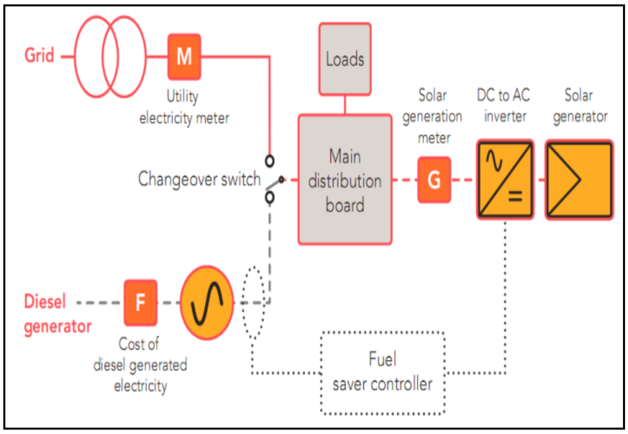


Figure 6: PV – diesel integrated systems

The solar fuel saver ensures that the generator is always operating at or above its minimum output which is 25-30% of its rated apparent power as shown in figure (7). If the load drops below this value, then the solar fuel saver simply reduces the total power output of the grid inverters of the PV generator.

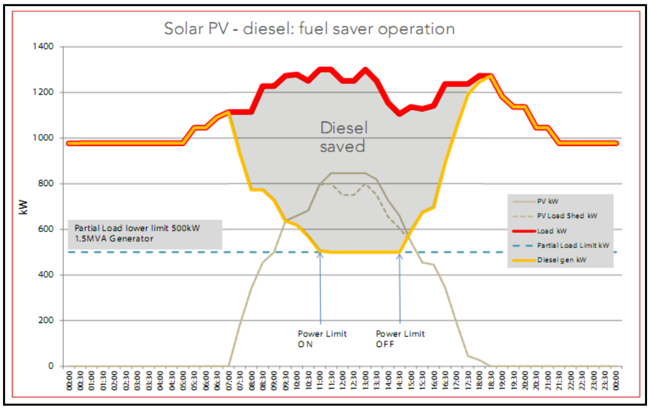


Figure 7: PV – diesel integrated load profile

The diesel generator must be large enough to accommodate the demand when the PV generation drops due to intermittent clouds. The diesel generator sees the PV input to the system as load reduction and reacts accordingly in order to maintain system frequency and consistent power flow.

II.c: AC-coupled SPV systems

In these systems, the SPV is connected to the grid or a diesel generator through bidirectional battery inverter at the AC bus as shown in figure (8).

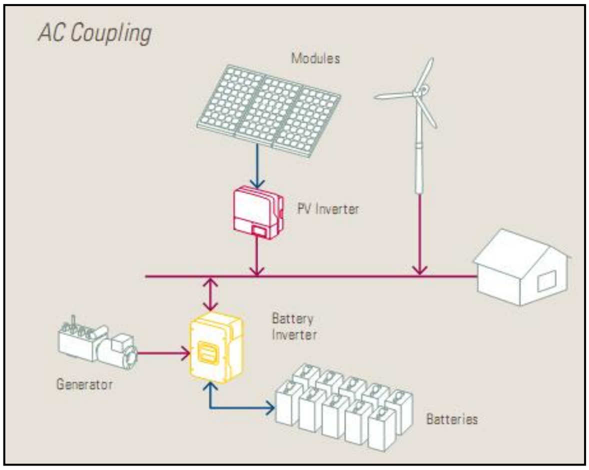


Figure 8: AC coupled SPV systems

Table (4) lists the advantages and disadvantages of such system.

Table 4: Pros and cons of AC coupled SPV systems

Type of system	Pros.	Cons.
System 2: **AC coupled SPV system with battery backup**	• Surplus energy can be injected into the main grid. • Can supply power to loads during outage of grid power thanks to the battery backup • Reduces electricity bill and fuel bill for generators	• Affected by grid instability. A backup power source is needed such as batteries and / or generators which adds extra cost to the system • Requires a space for batteries and battery inverters

The system *first priority* shall be for the solar generation. The grid shall be on the *second priority* supplying the balance of current when the solar power is smaller than the protected load power. If there is excess PV generation, the extra power shall be exported to the internal hospital network through the bidirectional meter. When the solar power is smaller than the protected load power and the grid is off, the battery bank shall be on the *third priority* supplying the balance of current down to 50% DOD. If there is excess PV power, the batteries shall be charged till 100% state of charge (SOC). A one way directional energy meter shall be placed at the output of the grid inverters to measure the aggregate PV generation, a bidirectional meter shall be placed at the utility side on the input of the battery inverters to measure the amount of excess solar energy fed to the internal hospital network and the amount of energy balance consumed by the protected load.

A directional meter shall be placed at the protected load side to measure the demand energy consumption.

II.d: DC-coupled SPV systems

In these systems, the SPV is connected to the grid or a diesel generator through bidirectional battery inverter at the DC bus as shown in figure (9).

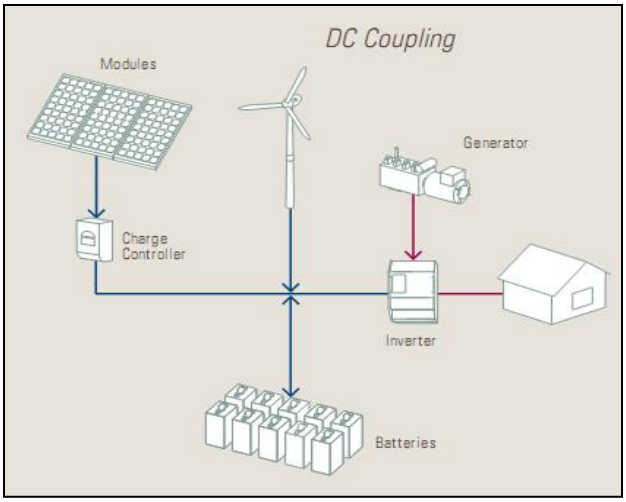
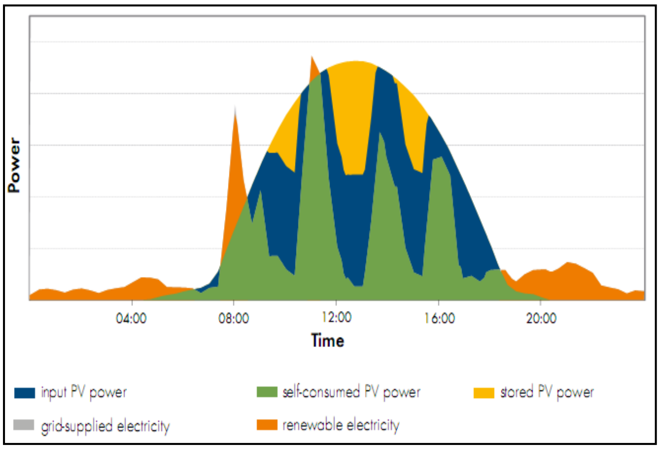


Figure 9: DC coupled system

When the grid is off, the system works in inverter mode. It discharges power from the DC bus with first priority for solar generation. The battery shall be on the second priority supplying the balance of current when the solar power is smaller than the protected load power. If there is excess PV generation, the batteries are charged till 100% state of charge (SOC) as shown in figure (10).

When the batteries are full, the charge controller shall limit the PV power. When the grid is on, the loads are supplied from the AC and DC power simultaneously.



Electrical System limitations	
System Location	NASER Hospital -Khanyounis
System Load demand	216kWh/day
System PV size at STC	50.4kWp
Roof area required	650m2
PV modules location	Roof mounted
Battery Bank energy	432kWh C-10
Allowable DOD	50%
Battery inverters rating	63kW at UPF
Grid inverters rating	52kW at UPF

Type of system	Pros.	Cons.
System 3: **DC coupled SPV system with battery backup**	• Does not require net metering agreement. • Can supply power during outage of grid power • Reduces electricity and fuel bill • Not affected by grid instability	• Surplus power cannot be utilized when load is low and batteries are full. • Requires space for batteries and battery inverters • Requires battery replacement but after long interval depending on batteries technology

Figure 10: Battery charging from excess PV power

Table (5) lists the advantages and disadvantages of such system.

Table 5: Pros and cons of DC coupled SPV systems

III- System Design and simulation results

The SPV system adopted for the case study was AC coupling with battery backup. The block diagram of the system is shown in figure (11)

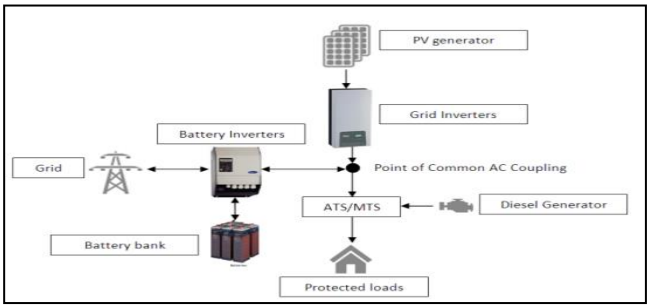


Figure 11: AC coupled SPV system block diagram

The system was designed to meet the electrical limitations listed in table (6).

Table 6: Case Study electrical system limitations

The system's DC and AC energy production is shown in figure (12) with a daily average AC production of over 200kWh and 73MWh per year.

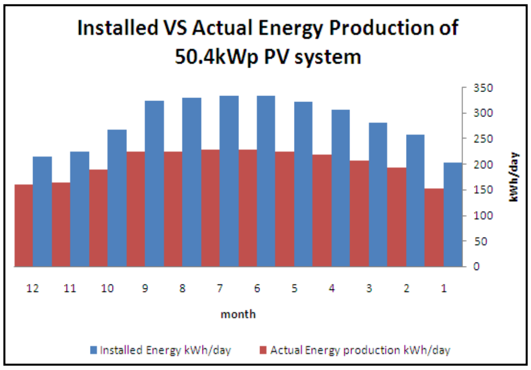


Figure 12: Simulated energy output of SPV system

The roof was retrofitted by BAPV system as shown in figure (13)

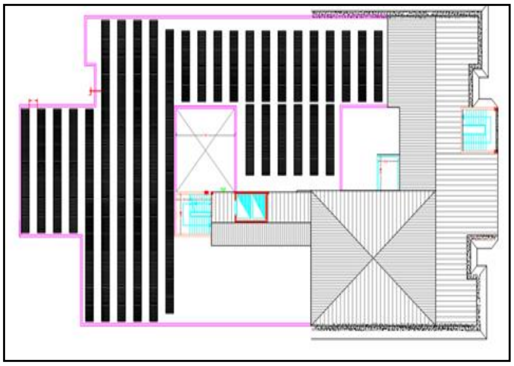


Figure 13: Roof mounted SPV layout

The steel structure was designed so that the inter-row shading is avoided around the year as shown in figure (14)

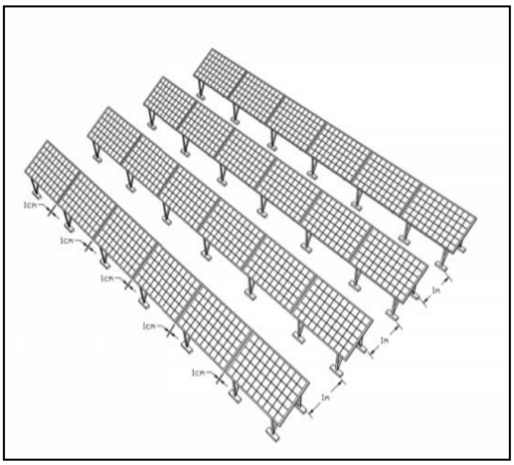


Figure (14) steel structure inter-row spacing

Table (7) records the brand and quantity of the main components used in the construction of the project.

Table 7: Equipment used in project implementation

Equipment	Brand and quantity
Solar modules	160*315Wp Suntech poly crystalline-China
Grid inverters	5*10000+ VA 3ph MPPT STECA-Germany
Battery inverters	9*7000VA STECA - Germany
Batteries	72*2V*3000Ah BAE OPzV-Germany
Steel structure	Hot galvanized steel-angle type
CFL lamps	250 LED efficient lamps – LIPER Germany

IV- ECONOMIC IMPACT

The system is expected to generate a total of 73MWh/yr substituting the combined energy supply from the public grid and the local diesel generator. In this case, the calculated annual savings when operating the SPV system shall be in the range of 19kUSD. This means that the investment cost shall be retrieved immediately by the end the first twelve years of operation.

V - CONCLUSION

Solar Photovoltaic systems has played an important role in the solar industry because solar PV systems are clean, environment friendly and considered secure energy sources.

Based on the findings of SPV integration in existing power systems, it is highly recommended to utilize solar Photovoltaic system in a public building as a partial green solution to the shortage of generated energy in the Gaza Strip.

The paper compared different types of SPV systems implemented worldwide and focused on the advantages and disadvantages of each system while discussing the suitability and conformity of each system to local electrical environment in the Gaza Strip.

The case study presented in this paper dealt with retrofitting AL-NASER hospital in Khanyounis by 50.4kWp Building Applied Photovoltaic (BAPV) design featuring AC-coupled SPV system with battery and diesel generator backups as spinning reserves.

Energy efficiency was also addressed by replacing existing inefficient lamps with LED lights resulting in lighting power reduction by almost 60%.

The aggregate PV system is expected to generate a total of approximately 73MWh per year contributing to major economic impacts comprising reductions in electricity bill and diesel fuel consumption and Green House Gas (GHG) emissions.

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